

# AN IMPORTANT PAPER ON IRON.

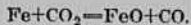
## The Magnetization of Iron Ore Considered.

A Paper Read by Mr. Clemens Jones, of Hokenaqua, Pa., at the Fall Meeting of the American Institute of Mining Engineers at New York September, 1890.

The peculiar property of the lodestone has been known for many centuries. It was very early observed that, by contact with it, iron is magnetized; and it is needless to dwell here upon the history allied to this discovery, now constituting the wonderful science of magnetism.

Deposits of magnetic ore are distributed all over the world. The ore is sometimes very rich and comparatively free from gangue, sometimes sparsely disseminated in the native rock. These bodies of lean ore often cover large areas. Modern ingenuity has utilized the principle of the magnet, originally derived from the ore itself, and really belonging to the time of Plato and Theophrastus, to separate the magnetic ore particles from the rock which has previously been crushed. This process recovers the ore in the state of a concentrate very rich in iron and, in some cases, desirable for Bessemer purposes. The magnetic separator is no longer a novelty. It was only at the last meeting of the Institute in New York, that Messrs. Birkinbine and Edson (Trans., xvii., 728) and Mr. Robert Cook (Ib., 599) described some of the principal designs of apparatus in use.

E. S. Dana classifies the natural magnetic minerals in the following order: magnetite, pyrrhotite, franklinite, almandite and minerals "containing considerable FeO." Of these, ferrous oxide, or magnetite, is the type. The proportionate amount of ferrous oxide essential to magnetize the compound, is not established. Ferrous oxide appears to be the only magnetic oxide of iron. Tissandier, (Compt. Rend., lxxiv., 531) produced ferrous oxide in the anhydrous state by the action of carbon-dioxide on pure iron at a red heat, according to the equation:



This is black, crystalline and magnetic. Heated to redness in the air, it is converted into  $\text{Fe}_2\text{O}_3$ . Sidot (Compt. Rend., lxxvii., 175) has also produced an oxide exhibiting magnetic polarity, by heating ferric oxide to a temperature not sufficient to fuse it, in an earthen tube placed in the magnetic meridian.

A. Frenzel (Jahrb. f. Min., 1874, p. 683) accidentally obtained small rhombohedra, slightly magnetic, by igniting a precipitate of ferric hydrate.

The presence of ferrous oxide in magnetite, whether as a molecular constituent of the compound, or as an independent molecule, seems to communicate the property of magnetism.

Magnetic oxide of iron, as an artificial product, is considered to result from the direct action of carbon dioxide. In simple determinative blow-pipe work, the reducing-flame alone, or with the aid of alkaline carbonate, produces magnetic particles, or slag-globules, from nearly all iron-minerals.

Spathic iron ores have long been known to exhibit, after roasting, magnetic properties—largely due, however, to the presence of metallic particles in the roasted ore. Carbon dioxide in the ore is also here considered an important factor. Of such ores, the ore-dressing at the zinc works at Pibram, Bohemia, described by Mr. Ellis Clark, Jr. (Trans., ix., 451), furnishes an illustration. The principle is here used for the separation of iron oxide from zinc-blende.

"These are separated from other material by the ordinary concentration processes, and are then in the form of a powder, the grains being less than 1 millimeter in diameter. This powder is composed of spathic iron-ore and zinc-blende, and is roasted in a small oven, with frequent stirring, for an hour, when the ore is rendered sufficiently magnetic."

It is then separated by a magnetic separator, and the zinc-blende is thus recovered.

In nearly all cases of the carbonates of iron similarly treated, minute globules of metallic iron are contained in the roasted oxide. Furthermore, the expulsion of the carbon dioxide contained in the ore, with contact of carbon at a certain heat, approximates to the conditions of the blast furnace and favors the reduction of part of the ferrous oxide to the metallic state. The roasted carbonate is always strongly magnetic. But, from the fusible nature of the ore, it is extremely difficult to prevent it from melting during the process, so that nearly all the associated minerals assume the form of "clinkers" with the ore. This circumstance, together with the expense of crushing the ore sufficiently fine, makes the magnetic separation of iron oxide from the gangue ore unprofitable in such cases. At Pibram, zinc-blende is sought, and the oxide of iron is a secondary product.

Hematite is sometimes magnetic, and, according to Dana, even magnetite-polar—of course, as an accidental occurrence, other than in crystallized specimens. On account of its rarity, as well as the feebleness of the attraction it presents, magnetic hematite is not available for practical purposes. Martite, the isometric ferric oxide which is supposed to be a pseudomorph after magnetite, is attracted by the magnet. The famous ore from Marquette in the Lake Superior region, abounds with crystals of martite. The ore from the Juragua mines, in Cuba is in part magnetic. Payalite,  $\text{FeSiO}_4$ , is magnetic.

The anhydrous oxides of iron in general are magnetic. Of all the hydrous oxides of iron, not one is magnetic. Brown hematite or limonite (usually which gothite and turgite are (usually associated), as well as the sub-varieties of hydrous oxides, are non-magnetic, and have no effect upon the magnetic needle. The composition of these oxides is:

Limonite..... $2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$ , or  $14.4$  Gothite..... $\text{Fe}_2\text{O}_3 + \text{H}_2\text{O}$ , or  $10.1$  Turgite..... $2\text{Fe}_2\text{O}_3 + \text{H}_2\text{O}$ , or  $5.6$

The importance of the brown hematites is indicated by the amount of such ores consumed in the manufacture of iron in this country and abroad. At

one time brown ore was considered indispensable for the production of foundry-iron. Prior to the development of the Lake Superior hematite regions, brown hematite was the chief ore in use in America. It occurs abundantly throughout Germany. "It supplies by far the greater number of French iron-workers; and it occurs also in Spain, Russia," (Crookes and Rohrig, Treatise on Metallurgy, p. 332) etc. In England the famed Forest of Dean supplied a great abundance of it. There are still vast bodies of the brown varieties unworked in England, and in this country they occur in nearly every State in the union. Since the advent of the rich Lake Superior hematite-ores, hundreds of productive brown hematite ore-mines have been abandoned; and there are still numerous undeveloped beds too lean to be handled profitably. In Pennsylvania the mines of Lehigh and Northampton counties have furnished for quarter of a century the raw material of nearly half the iron made in the Lehigh Valley.

With the exception of the oolitic varieties, the localities named may be considered to represent all of the varieties of brown-hematite ores. At present only the better grades are in use, and of these the supply is limited. An investigation of the quality, product and yield of thirty of these mines for the year 1877, undertaken by the writer, showed that over 100,000 tons of this ore, represented by fully 500 samples and analyses, averaged only 37 per cent. of metallic iron. Three-quarters of this was wash-ore. The bulk of this ore, which will fairly represent the majority of this class of mines in the United States, will carry about 34 per cent. of metallic iron in the wash-ore.

Examination of the iron oxide, or ore proper, shows it to contain from 45 to 60 per cent. metallic iron, which, in the wash-ore, is, in many instances, reduced below a marketable standard by the admixture of foreign material, chiefly quartz-gravel, slates and clay.

Separation of the ore is a problem presenting many-sided difficulties that have never been successfully overcome. Water-jigs and specific-gravity separators of innumerable designs have been invented for the purpose all over the world. But the very best results with these machines fall short of obtaining the ore entirely separated without loss in the tailings. A concentrate carrying 42 per cent. of metallic iron is a fair economical result from these machines, and, except with unusually rich ores, 45 per cent. of iron is seldom obtained. The only satisfactory solution of the problem lies in the recovery of all of the ore proper, entirely free from foreign material.

Some experience a few years ago with a method of water-separation acquainted me with the futility of attempting this result by that means or any other at that time known. With the modern demand for the rich material, it is easy to anticipate that the blast-furnace cannot exist among abandoned ore-beds. And the fact must not be overlooked that in this country nearly all of the older blast-furnace plants were located within or adjacent to the brown-hematite regions. A perfect method of concentrating would mean a survival of the brown-hematite ore as a source of supply.

On rapidly drying a small sample of limonite over a powerful Bunsen flame on one occasion, I observed that the smaller particles were magnetized. Could the ore be magnetized? A trial on a more practical scale convinced me that such was the case. I then experimented with several different ores, and found that all the ore-particles were so strongly affected as to permit their complete separation by means of a magnet.

Naturally, a series of experiments followed, in every instance giving the same results. My attention was then directed toward finding out the conditions as well as the cause of the phenomenon. This led me to the conclusion that the agency of heat in the presence of carbon or carbon dioxide magnetizes the hydrous oxides of iron.

Further on I will endeavor to qualify this statement; but before beginning its discussion it may be interesting to allude to the practical method and the results, from a commercial standpoint, of some of the experiments.

The ore is placed in a convenient receptacle and merely roasted by the usual process, using either solid or gas-fuel. It is undesirable to use much heat, since at a temperature of cherry red magnetization is fully imparted. The ore is drawn as fast as it reaches this temperature, and is at once ready for magnetic separation.

In the following list, for obvious reasons, the ores are designated alphabetically:

Iron in Crude Ore	Iron in Concentrate	Iron in Tailings	Of Ore Recovered as Concentrate
Per cent.	Per cent.	Per cent.	Per cent.
A, 40.98	55.88	.....	.....
B, 34.32	51.72	.....	.....
C, 38.04	45.24	.....	68
D, 40.63	50.04	.....	80
E, 20.30	46.32	5.21	55
F, 40.00	53.71	.....	65
G, 49	60	.....	80
H, 37.06	50	.....	80
I, 41.31	52.56	.....	85
J, 35.35	55.04	.....	60
K, 33.55	48.63	2.46	70
L, 31.31	48.78	5.20	70
M, 39.84	51.29	5.00	78
N, 42.55	55.36	5.76	86
O, 43.84	55.61	.....	70
P, 42.96	54.43	.....	85

A, B, C, D and E are from Pennsylvania, A and B being wash-ore; C, washed and jigged ore; D, a fine refuse-sand; and E, a similar material; F, an ore separated by a Bradford jig; G, ore from a Northampton County, Pa., mine; H, the tailings rejected by a new jig; I, a Pennsylvania ore; J, a lot of six cars of ore "condemned" at the works; K and L are from the same mine in Pennsylvania and impossible to separate by water-jigging; M is a mixture of fine ore from Pennsylvania mines; O, an ore from Connecticut, and P, the fine ore from a large mine in New York.

The commercial success of treating ores in this way depends on the three items: cost of wash-ore; cost of roasting; cost of concentration. The first may be considered to range from 75 cents to \$1.50 per ton, according to locality. The second item will be fully covered by the following statement, taken from the books of a large company exclusively engaged in roasting carbonate ores, and

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at that time under the most capable management.

Actual cost of roasting and handling per ton of ore:

ROASTING ORE.			
	1886.	1887.	1888.
Labor, including car and topman.....	\$0.0083	\$0.0073	\$0.0811
Supplies.....	0.0024	0.0032	0.0091
Coal.....	0.0725	0.0750	0.0748
	\$0.1632	\$0.1455	\$0.1650
Clum, per ton.....	2.00	2.10	2.25
Average cost, \$0.1600.			
About one ton of culm used to 30 tons of ore.			

### HANDLING AND WHARF EXPENSES.

	1886.	1887.	1888.
Labor, including engineer and teamster.....	\$0.0514	\$0.0439	\$0.0720
Supplies and coal 0.0177	0.0132	0.0169	
Team.....	0.0040	0.0062	
Repairs, etc.....	0.0046	0.0025	0.0029
	\$0.0731	\$0.0636	\$0.0980
Average.....		\$0.0700	
Average total cost.....		0.2300	
Per ton of ore treated.			

The third item remains to be determined, namely, the cost of concentration, including royalty on the process. This would be 2 cents per ton for concentrating and 25 cents royalty. Taking as an example ore "K" in the foregoing list, the cost of the concentrated ore would be as follows:

Cost of $\frac{1}{2}$ ton ore.....	\$2.25
"    roasting.....	30
"    concentration and royalty.....	27
	\$2.88

At a yield of 48 per cent. iron, this is 6 cents a unit, or, in sound numbers, 6.00 to the ton.

To determine the extent to which the other constituents of the ore were affected, I tested several of the ores, of which two examples will suffice. They gave the following results:

Ore	Raw.	Concen.	Tailings.
Iron, 20.30	46.32	5.21	
Phosphorus, 0.12	0.30	0.09	
Ore M.			
Iron, 31.31	48.87	5.20	
Silica, ———	20.25	83.20	
Manganese, ———	2.20	1.18	

The surprisingly small amount of ferrous oxide in the magnetized ore leaves the question, whether magnetization is wholly due to its presence, very uncertain. In the list of ores given, G, carrying 60 per cent. of iron, which would be presumably high in ferrous oxide, contains but 3.07 per cent. of ferrous oxide. In some cases the raw ore contains nearly this amount. If the reduction caused by roasting were the sole cause, it would be reasonable to expect the exterior of the particle to be the magnetized portion. But lumps of the roasted ore having been broken, small pieces, carefully selected from the inside of the lumps, showed in some cases even more strongly marked magnetic properties.

A number of trials with the anhydrous oxide, both red and specular hematites, conducted in precisely the same manner, gave no evidence whatever of resulting magnetization. Crystallized specimens remained likewise unaffected. While the porous character of the brown hematite would permit permeation by reducing the gases, it is difficult to understand how such minute deoxidization could magnetize it so strongly. Moreover, the magnetization appears to be permanent. Samples which I have kept for over a year in contact with air have preserved the quality unimpaired. Cooling the red-hot oxide in water affects it somewhat, but it is still capable of responding through that medium to the attraction of a magnetic field.

The phenomenon seems to be connected with the expulsion of the combined water, and I think is largely dependent on its physical separation from the ore. During the process some of the oxides glow quite strongly. The raw oxide, when heated to redness in a closed glass tube, gives off a small amount of carbonic acid with its water, but is only feebly magnetic. There is no apparent evidence that ferrous oxide is produced by decomposition of the water. The only statement now possible is that the hydrated oxides of iron become magnetized at a red heat in contact with carbon or carbon dioxide.

It may be worth noting that the idea of employing a magnetic separator in a process for "manufacturing cast steel and malleable iron of a superior and uniform quality directly from ores" was announced some years ago. The curious supposition on which it was based was, that when "impure ores" are brought to a white heat in a furnace (thereby producing metallic sponge), they can be separated from "pure ores" by the "simple mechanism of revolving magnets." Some of the "noxious elements" thus to be eliminated were "titanic acid, vanadic acid, chromic acid, sulphuric acid, sulphur phosphorus, phosphoric acid, silicic acid, silicates." The resulting product was to be simply melted.

It is of course a logical deduction, that all hydrous ores of iron become magnetic in the blast-furnace, and that at the proper zone even anhydrous hematite does so. Ore concentrated as above described is peculiarly adapted to use in the blast-furnace. Before the ore-particles reach a red heat in the process of roasting, violent decrepitation takes place, thus breaking or splitting up into small fragments all lumps of ore. This state is most desirable for rapid reduction in the blast-furnace, and, aided by the easy fusibility of the ore, offers the most favorable conditions for "driving" and regularity of work.

The subject-matter outlined in this paper is embraced in a process on which application for letters-patent has been made.

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ARRIVE AT ROANOKE.  
5:00 p. m. Daily—Memphis Express, from Hagerstown and the North. Through Pullman sleeping cars from New York and Philadelphia to Chattanooga and Memphis via Harrisburg, Hagerstown and Roanoke.  
7:40 a. m. Daily—New Orleans Express from New York, Philadelphia and Baltimore, making connection through to the South. Carries through Pullman palace buffet sleeping car from Philadelphia to New Orleans, without change, via Harrisburg, Hagerstown, Roanoke, Cleveland, Calera and L. & N. R. R.  
LEAVE ROANOKE.  
5:45 a. m. Daily—Baltimore Express from all points south through Washington, Baltimore, Harrisburg, Philadelphia and New York. Carries Pullman palace buffet sleeping car from Roanoke to Philadelphia without change, via Hagerstown and Harrisburg.  
7:20 p. m. Daily—New York and Philadelphia Express, from Memphis, Chattanooga and all points south. For Philadelphia and New York. Carries Pullman palace buffet sleeping cars through to Philadelphia and New York via Roanoke, Hagerstown and Harrisburg.  
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#### NORFOLK & WESTERN RAILROAD.

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WEST BOUND.  
LEAVE ROANOKE.  
10:05 a. m. Daily, arrive Bristol 4:05 p. m. Stops at all stations connecting at Radford with trains on New River Branch arriving at Pocahontas at 3:35 p. m.  
5:45 p. m. Daily, arrives Radford 7:25 p. m. connecting with New River Branch at 7:25 p. m. for Bluefield and Pocahontas; arrives Pocahontas 10:50 p. m. Arrives Bristol 11:25 p. m., connecting with E. T. V. & G. R. R. for all points south and west. Has Pullman Palace Sleeper Roanoke to Memphis, with out change.  
7:55 a. m. Daily, arrive Radford 9:1 a. m., connecting with New River Branch, leaving Radford 12:10 p. m. Arrive Bristol 12:40 p. m., connect with E. T. V. & G. R. R. for all points south and west; has Pullman Palace Sleeper from Roanoke to New Orleans without change.

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LEAVE ROANOKE.  
5:25 a. m. Daily, for Lynchburg, Petersburg, Richmond, (via Petersburg and R. & P. R.) Norfolk and intermediate points; connects at Lynchburg with V. M. R. R. for Washington and the East, leaving Lynchburg 7:40 a. m. daily. Arrive Norfolk 2:00 p. m., connecting with steamer lines Baltimore and New York.  
10:10 a. m. Daily, arrives Lynchburg 11:50 a. m., connecting with V. M. R. R. for all points north, arriving Washington 7:05 p. m.; arrives Petersburg 4:20 p. m.; arrive Richmond, via R. & P. R., 5:05 p. m.; arrives Norfolk 7:00 p. m.  
3:45 p. m. Daily, for Lynchburg at intermediate stations; arrives Lynchburg 5:40 p. m.  
7:20 p. m. Daily, for Lynchburg at intermediate stations; arrives Lynchburg 9:20 p. m.  
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